

CRASH INJURY EVALUATION

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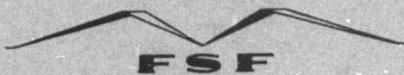
U. S. ARMY

AC-1 DE HAVILLAND CARIBOU

Ft. Rucker, Alabama

21 January 1960

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AVIATION CRASH INJURY RESEARCH

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U. S. ARMY AC-1 DE HAVILLAND "CARIBOU" EVALUATION

**Ft. Rucker, Alabama
21 January 1960**

REPORT OF CRASH INJURY EVALUATION

**A/CIR-14-PV-121
October 1960**

FOR

**United States Army
Transportation Research Command
Contract DA-44-177-TC-624**

AVIATION CRASH INJURY RESEARCH

**A Division of
Flight Safety Foundation, Inc.
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TREC Technical Report 60-62

U. S. ARMY AC-1 DE HAVILLAND "CARIBOU"

C R A S H I N J U R Y
E V A L U A T I O N

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FOREWORD

In its efforts to determine the crash survival aspects of aircraft accidents, Aviation Crash Injury Research (AvCIR), a division of the Flight Safety Foundation, is guided by certain criteria which it considers fundamental for the crash protection of aircraft occupants. The same criteria are also used to evaluate the crash safety features of mock-ups and prototypes.

Following is a brief description of these criteria:

1. **Crashworthiness:** The ability of basic aircraft structure to provide protection to occupants during survivable impact conditions.
2. **Tie-down chain:** All the components of the occupant seating and restraint system including the seat belt, the shoulder harness, the seat structure, the floor, and all related anchorages.
3. **Occupant environment:** The injury potential of all objects and structure within the occupant's striking range.
4. **Transmission of crash force:** The manner in which crash forces are transmitted (magnified or attenuated) by intervening structure to the occupants.
5. **Post-crash factors:** Post-crash fire, inadequate emergency exits, poor ditching characteristics, etc.

For a more elaborate discussion of crash safety criteria, reference is made to Appendix I.

BACKGROUND

A crash injury evaluation of the DeHavilland DHC-4, U. S. Army AC-1 DH "Caribou" was conducted by AvCIR, a division of the Flight Safety Foundation, on January 21, 1960, at the request of the U. S. Army Transportation Research Command (TRECOM).

The purpose of the evaluation was to:

1. Evaluate the overall crashworthiness of the basic aircraft structure.
2. Determine the existence, if any, of features which could lead to or prevent unnecessary exposure of crew members and passengers to serious or fatal injury in the event of a survivable-type accident.
3. Make recommendations for remedial action in the areas where deficiencies exist or are believed to exist in order to improve the overall crash safety aspects of the aircraft.
4. Note the existence of desirable crash safety features.

The above work was accomplished through a detailed evaluation of the entire aircraft, its components and equipment, in combination with references to technical manuals and the pertinent military specifications.*

This is the final report of the crash injury evaluation.

* Additional copies of the photographs used in this report may be obtained by forwarding request to USA, TRECOM, Fort Eustis, Virginia, Attn: RCO.

SUMMARY

The crash injury evaluation of the U. S. Army AC-1 DH "Caribou" disclosed several desirable crash safety features including a limit landing gear strength which permits a vertical rate of descent of 14 feet per second; the location of the fuel cells outboard of the engine nacelles; troop seat belt anchorages which are directly secured to basic aircraft structure.

The evaluation also revealed a number of crash safety deficiencies in the crew and troop seats, litter installation, number and location of emergency exits in the main cabin, and the related Military Specifications.

Attention is invited to the remedial action suggested in the recommendations pertaining to these deficiencies.

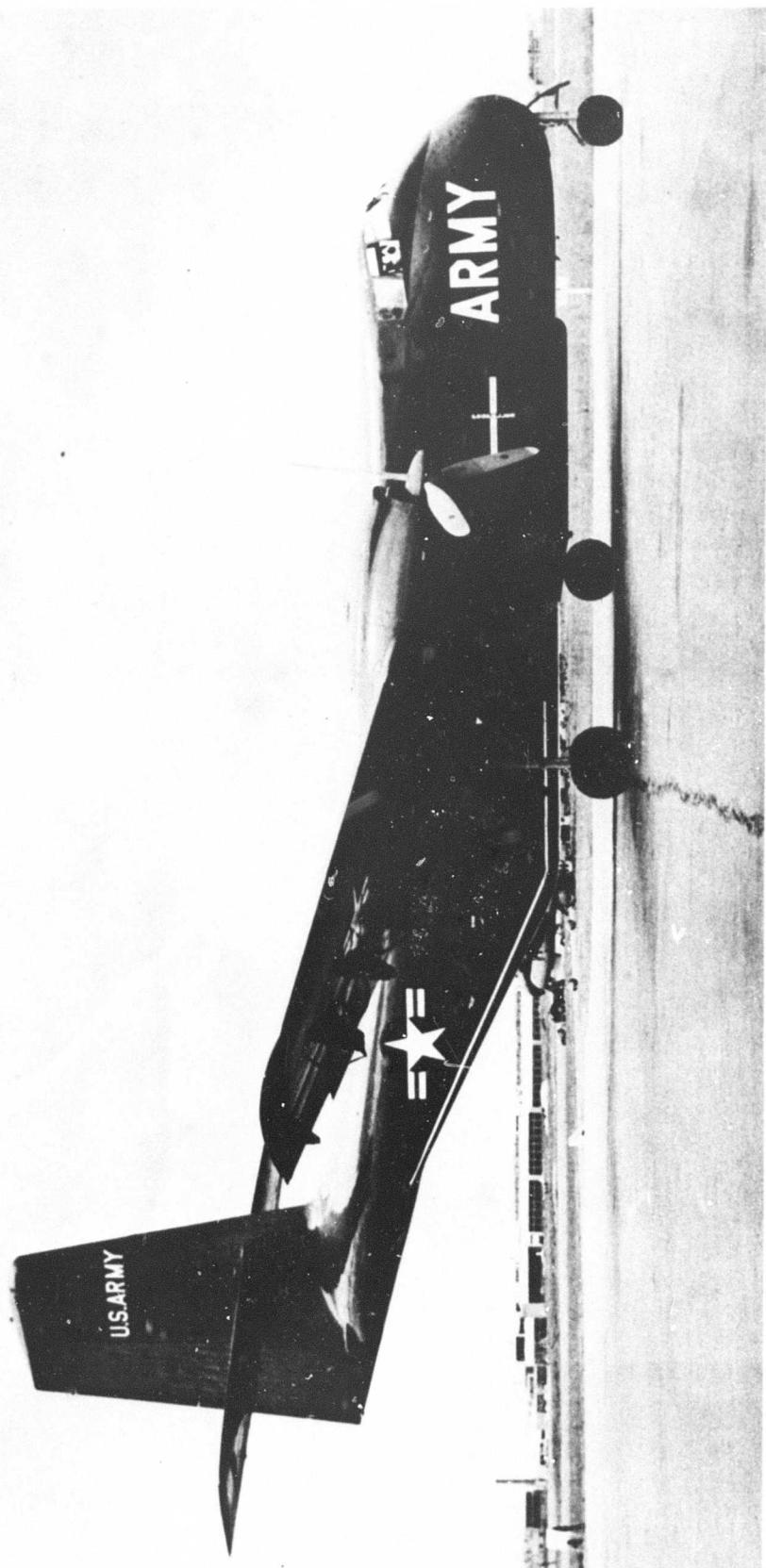


Figure 1. Front quarter view of the Caribou.

DESCRIPTION OF AIRCRAFT

GENERAL

The AC-1 DH "Caribou" is a twin engine STOL transport aircraft for U. S. Army support missions (Figure 1). It carries a crew of two and has accommodations for 32 troops or 14 litters and 8 seats (Figure 2).

The mission of this aircraft is to serve as an Army vehicle in providing support to military operations in forward areas in any of the following roles:

1. Transportation of military supplies and personnel to and from forward areas using short, improvised airstrips.
2. Aerial supply.
3. Evacuation of casualties.

The gross weight of the Caribou is 26,000 pounds. The payload varies between 2,000 and 7,000 pounds depending upon the desired range. The overall dimensions of the aircraft are given in Figure 3. Two reciprocating engines (Pratt and Whitney Model R-2000-13) are installed in wing mounted nacelles and are interchangeable.

The aircraft is designed and has been certificated in accordance with the requirements in CAM 4b* "Airplane Airworthiness, Transport Categories" with the exception of the troop seat installation.

FUSELAGE

The fuselage structure consists of three principal assemblies: the front section, extending from the nose aft to the bulkhead dividing the flight compartment from the cargo compartment; the center section which includes the entire cargo compartment; the rear section comprising the rear cargo door and the rear fuselage.

* CAM 4b, Civil Aeronautics Manual 4b, Airplane Airworthiness; Transport Categories, Federal Aviation Agency, U. S. Government Printing Office, Washington 25, D. C., May 1, 1960.

WING GROUP

The wing consists of a center section which continues through the fuselage and carries the two engines nacelles. The left and right wing outer panels are attached to the center section directly outboard of each nacelle.

In addition to the power plants, the center section also supports the main landing gear. The fuel tanks are located in the outer wing panels. These tanks consist of ten flexible bag type rubber-nylon composition cells in each wing attached to the wing structure by snap fasteners.

CREW COMPARTMENT

The cockpit has accommodation for a pilot and copilot in a side by side seating arrangement and has dual controls. A "jump" seat can be installed to accommodate a third man in the cockpit (crew chief or troop commander) during flight only.

The flight compartment entry hatch is located behind and below the crew seats in the floor of the aircraft. It is unlikely that this hatch will be used for routine crew compartment entry and exit, unless bulky cargo prohibits more convenient access through the doorway in the bulkhead that separates the flight compartment from the cargo compartment.

CARGO COMPARTMENT

The cargo compartment (cabin) is equipped with removable seats, cargo tie-down fittings and installation provisions for litters. Its dimensions are approximately 28 x 6 feet at floor level and its cubic volume is 1,150 cubic feet. The large rear cargo doors, which are flight operable to facilitate aerial delivery or emergency exit, operate in two parts and provide access to the full floor width and the full ceiling height (74 inches).

The cabin is equipped with an emergency exit on the left side of the fuselage under the left wing and two doors on opposite sides at the aft end of the cabin.

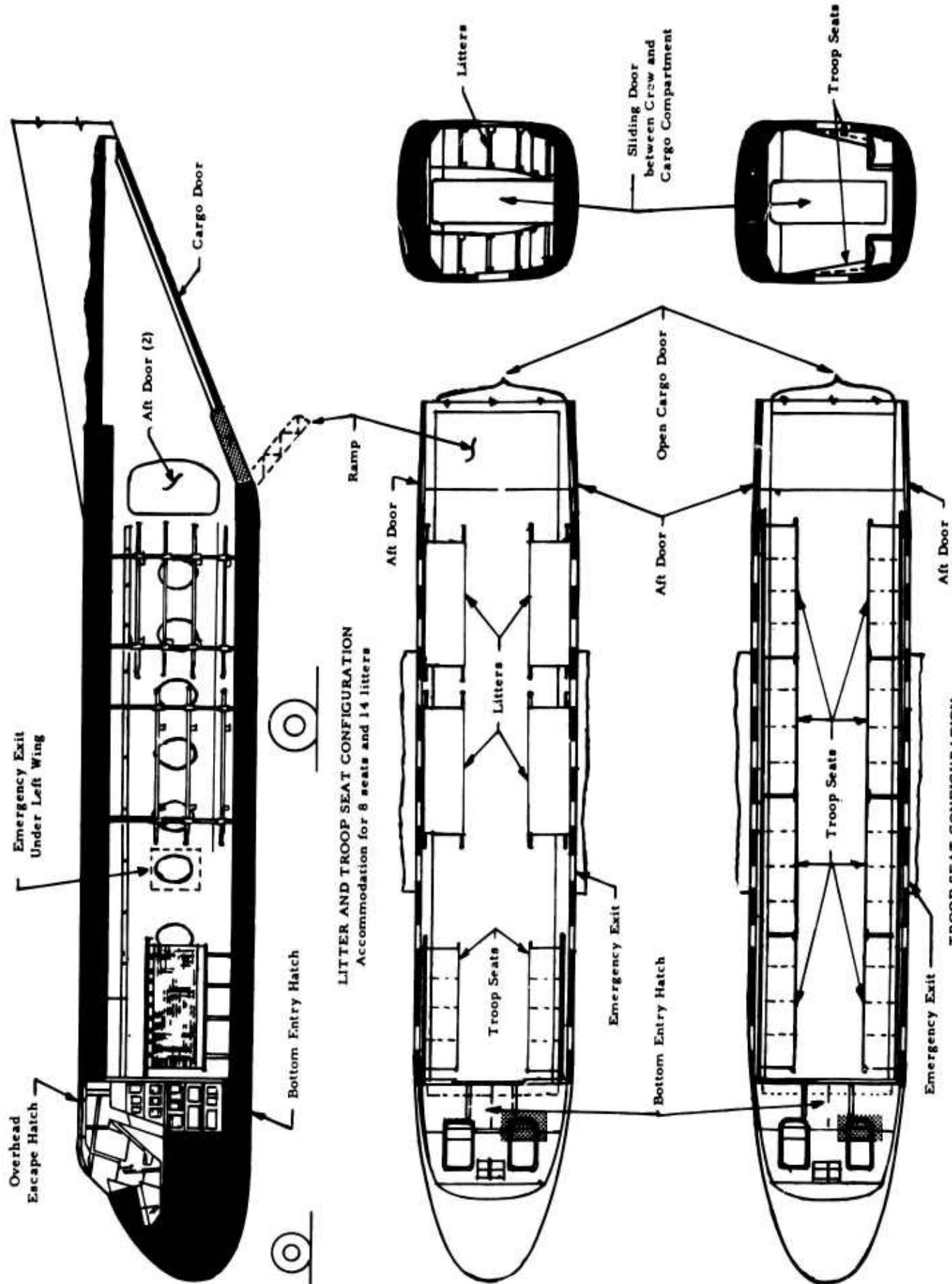


Figure 2. Cabin layout.

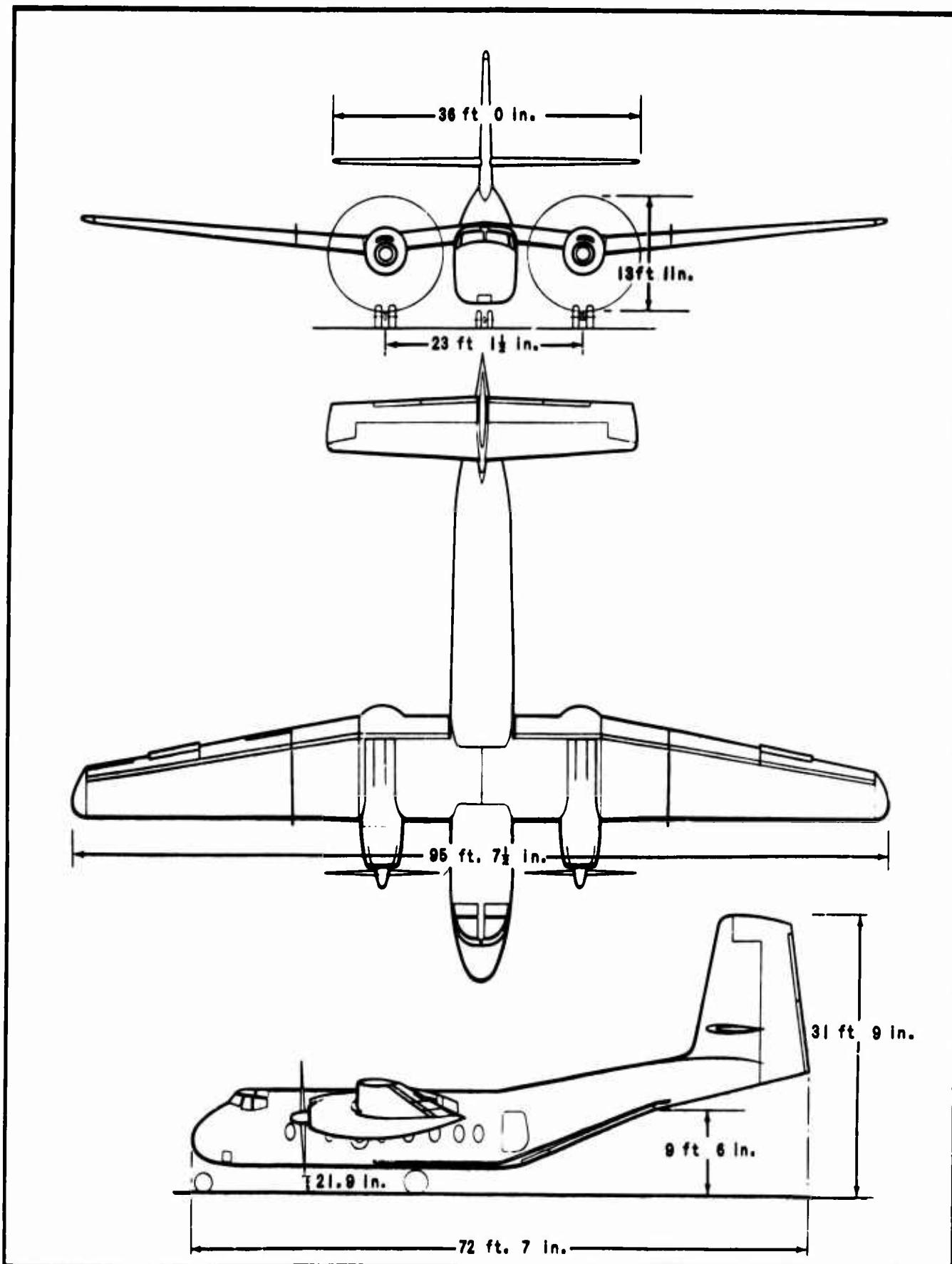


Figure 3. Three-dimensional view.

Section I

EVALUATION OF BASIC AIRFRAME

GENERAL

Although it is difficult to predict the behavior of the basic aircraft structure during a crash deceleration from a study of the available data, some impression of the aircraft's structural strength may be gained from an examination of the design criteria.

The aircraft is designed in accordance with the requirements of CAM 4b "Airplane Airworthiness, Transport Categories". However, the design achievement insofar as the structural maneuver and gust envelope is concerned exceeds the design requirement in CAM 4b for limit flight loads.

Since the Caribou has STOL capabilities and is designed for rough field operation, the limit ground load factors exceed those required in CAM 4b. At the design gross weight of 26,000 pounds, the limit landing gear strength and energy absorption capability permits a vertical rate of descent of 14 f. p. s. (CAM 4b requirement: 6 f. p. s. at the design take-off weight).

This gives the basic aircraft structure its main strength in the inverted U formed by the main landing gear and the connecting wing center section (Figure 4) and indicates the advisability of making a crash landing with the main landing gear extended, regardless of terrain.

Although some of the floor members are designed to serve as longitudinal skids in the event of a belly landing, caution should be used when executing a wheels-up landing as a result of landing gear malfunction. In this type landing the fuselage structure must support more than half the gross aircraft weight (wing-engines-landing gear-fuel) which may result in excessive loads during unflared-landing crashes.*

* G. M. Preston and G. J. Pesman, Accelerations in Transport-Airplane Crashes, NACA Technical Note 4158.

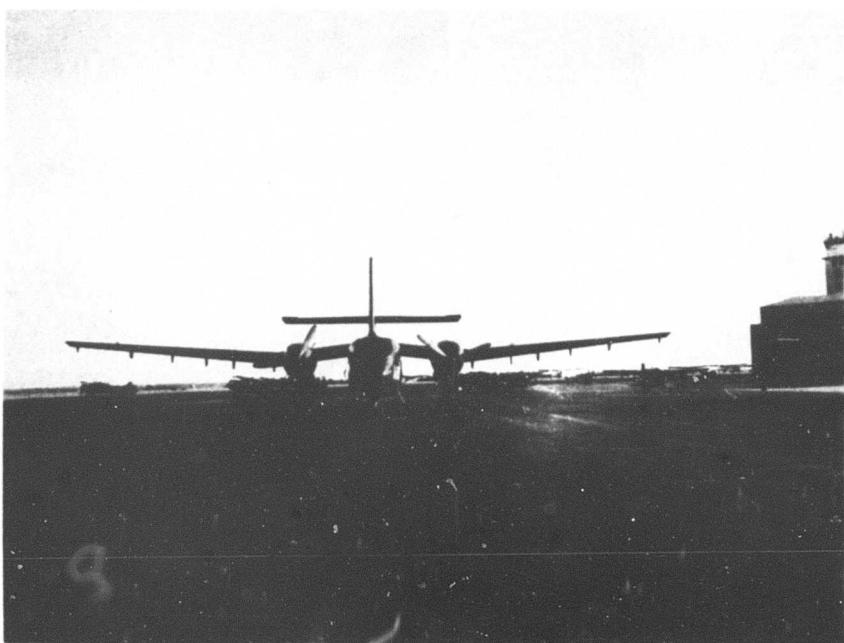


Figure 4. Front view of Caribou.

Therefore, a flat terrain should be selected and the aircraft should be flown in rather than dropped in to prevent crushing of the cabin compartment by the heavy super-structure.

Crash landings involving severe vertical impacts with the landing gear extended may result in the tearing free of the engines and engine mounts. However, it is impossible to predict what consequences such an occurrence would have on the survival aspects of the accident.

CONCLUSIONS

Based upon the evaluation of the basic airframe it is concluded that:

1. The design criteria and the design achievements are such that adequate crash protection may be expected in non-extreme impacts with landing gear extended.
2. Unflared-landing crashes with the landing gear retracted may cause excessive loads on the fuselage structure.

Section I

RECOMMENDATIONS

Based upon the foregoing conclusions it is recommended that:

- 1. If conditions permit, crash landings be made with the landing gear extended, regardless of the terrain used.**
- 2. If landing gear malfunction dictates a wheels-up landing, flat terrain be selected and the landing technique be aimed at minimum vertical load at touchdown.**

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EVALUATION OF CREW COMPARTMENT

PILOT'S AND COPILOT'S SEATS

The pilot's and copilot's seats in this aircraft are attached to floor tracks in a side-by-side arrangement. The seats are adjustable in the fore and aft direction by means of a frame which slides over two floor tracks. They are vertically adjustable in this frame by means of levers and springs (Figure 5). The seats are equipped with seat belt (type MD-2), shoulder harness (type MB-2), and inertia reel (type MA-1), all attached to the seat. This arrangement is not desirable from the crash safety point of view since the occupant restraint effectiveness depends upon the seat tie-down strength.

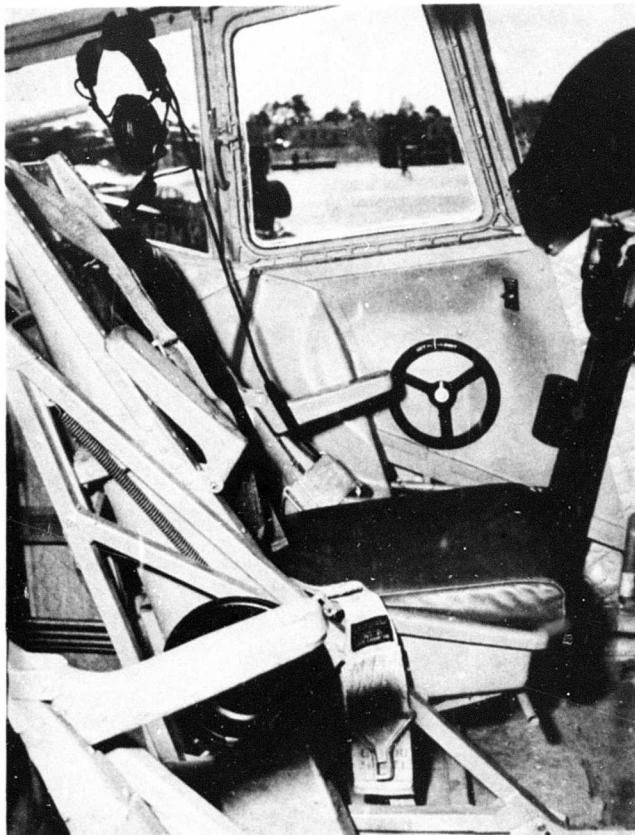


Figure 5. Pilot's seat.

Section II

Attachment of the seat belt and shoulder harness to basic aircraft structure would relieve the seat of much of the crash load during crash deceleration and offer some form of occupant protection even when the seat tie-down failed. On the other hand, it is realized that this would entail certain inconveniences for the occupant because vertical seat adjustment would always necessitate seat belt adjustment while shoulder harness adjustment might be necessary before or after vertical and/or horizontal seat adjustment. Based upon this analysis, it appears advisable to have the seat belt attached to the seat as presently attached.

The manner of shoulder harness attachment cannot so easily be decided. The advantage of attaching the shoulder harness to basic aircraft structure is unquestionable since it eliminates the torque on the seat exerted by a shoulder harness anchored to the seat. This advantage must be weighed against some of the problems that may be encountered.

One of these is the feasibility of attaching the harness to basic aircraft structure in this particular aircraft. A harness running straight aft over the top of the seat into a bulkhead immediately behind the seat would be ideal. However, the space behind the crew seats in the Caribou is occupied by equipment and is also used as a passageway to the overhead escape hatch. The shoulder harness could also be attached to the floor but this configuration has less advantage than the one just discussed because it does not relieve the strain on the seat back.

Another problem that must be considered is pilot's convenience. Although the inconvenience caused by a shoulder harness attached to basic aircraft structure is less pronounced than that of a floor-attached seat belt, it should be borne in mind that any solution which would discourage the use of the shoulder harness by the crew members should be avoided.

The matter of seat belt and shoulder harness anchorage would not create a problem if the seat tie-down criteria approached the limits of human G tolerance (so-called 40 G seats). In that case there is no objection to anchoring the restraint harness to the seat structure. The requirements for the crew seats in the Caribou do not meet these high standards and it seems therefore advisable to give serious consideration to increased occupant protection by anchoring the shoulder harness to basic aircraft structure.

The vertical seat adjustment system creates a hazard under certain conditions. A person (crew chief or troop commander) standing in the aisle behind and below the crew seats would probably support himself by placing his hand against the open frame work in which the seat moves up and down. This would expose his hands to injury in case of vertical seat adjustment by one of the crew members.

Section II

The crew seats and their attachments are designed to withstand the ultimate loads given in Table I which are based upon a 200-pound occupant. For comparison, the ultimate load requirements for passenger seats as specified in CAM 4b and NAS 809* are also given. These loads are based upon a 170-pound passenger. According to Technical Standard Order TSO C39**, NAS 809 applies to seats and berths manufactured for installation in civil aircraft with the exception of the sideward load requirements. These need not exceed the requirements in CAM 4b.

TABLE I
ULTIMATE LOADS FOR SEATS

	Acceleration Factors in G-units			
	Forward	Sideward	Upward	Downward
DH crew seats	20	3	3	7
CAM 4b passenger seats	9	1.5	2	4.5
NAS 809 passenger seats	9	3	2	6

Although the Model Specification states that these loads exceed the requirements of CAM 4b, TSO C-39, and NAS 809, it should be noted that this is not entirely correct. The side load strength of the crew seats exceeds the requirements in NAS 809 when expressed in pounds (600 pounds versus 510 pounds), but they are equal when expressed in G's. This is due to the fact that the Model Specification uses 200 pounds as the occupant's average weight while the CAM and NAS requirements are based upon an average passenger weight of 170 pounds.

* NAS 809, Aircraft Seats and Berths Specification, National Aircraft Standards Committee, Aircraft Industries Association of America, Inc., Washington, D. C., January 1, 1956.

** TSO C39, Aircraft Seats and Berths, Technical Standard Order, Civil Aeronautics Administration, Washington, D. C., January 4, 1957.

Section II

Considering the difference in type of operation of an airline transport and a military STOL aircraft in forward areas, it seems reasonable to expect that the crew of the latter would be provided more protection against sideward deceleration than passengers in an airline transport.

In addition, the observation can be made that the sideward as well as the upward strength of the crew seats is not in proportion to the forward strength (20 G's).

For a further comparison of the crew seat characteristics of this aircraft with military design requirements - although not applicable to this aircraft - reference is made to Appendix II.

CREW CHIEF/TROOP COMMANDER SEAT

To satisfy special military requirements provisions have been made for the installation of a folding "jump" seat to accommodate a third man (crew chief or troop commander) in the cockpit. This seat is to be placarded - INFLIGHT USE ONLY - and can be installed behind the crew seats, above the bottom entry hatch.

At the time of the evaluation the subject aircraft was not provided with a "jump" seat. In addition, the Model Specification does not give a further breakdown of required characteristics. The only significant information in this respect is that the Canadian Department of Transport will not approve this particular installation.

The Model Specification does not specify the installation of a seat belt in the "jump" seat, probably because this seat is intended for inflight use only. Since it may be expected that, occasionally, this restriction will be disregarded, the installation of a seat belt seems advisable. Further, other factors, such as turbulence and violent maneuvers, stress the need for a seat belt in this position.

MIL-S-5705, although not applicable to the Caribou, contains specific and rigid requirements for this type seat, including the mandatory seat belt.

COCKPIT ENVIRONMENT

The cockpit gives an "uncluttered" impression which is mainly due to the overhead location of the engine controls (eliminating the conventional control pedestal) and the stowable radio equipment which is located on a console between the crew seats and slides forward into the instrument panel (Figures 6 and 7).

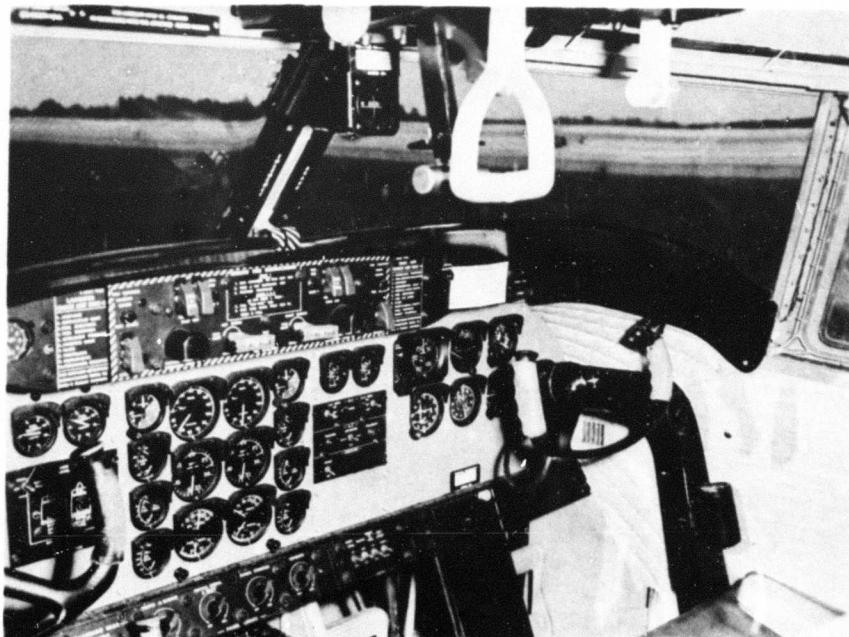


Figure 6. Right side of the cockpit, showing overhead location of engine controls.

Although the tie-down strength of this console could not be accurately assessed, it can be stated that its resistance against abrupt decelerations should be at least equal to that of the crew seats to prevent it from becoming a dangerous projectile or imposing an additional load on the adjacent seat attachments.

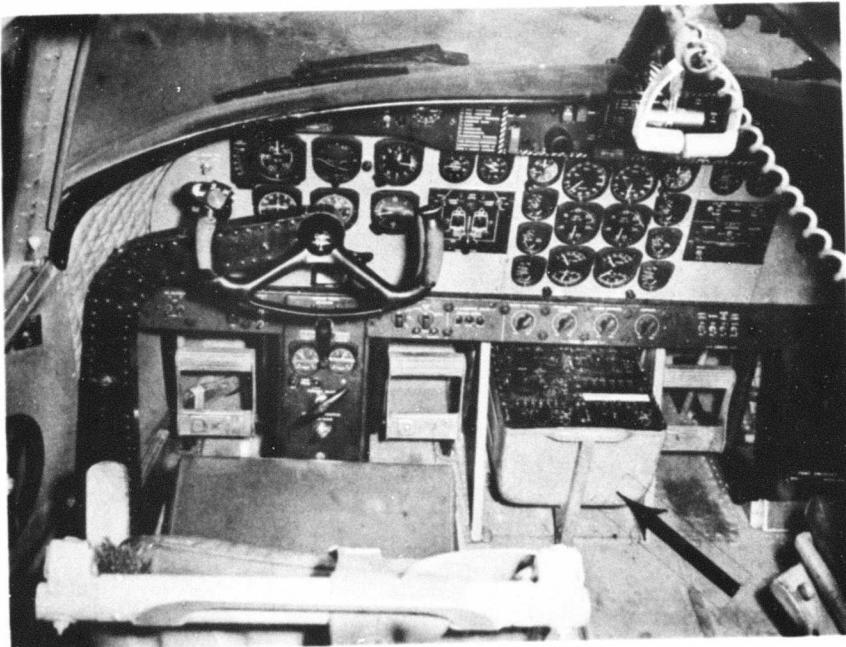


Figure 7. Left side of the cockpit, showing the stowable radio console between the pilot's and copilot's rudder pedals (arrow).

Instruments, controls, etc. are within convenient working distance of the pilot. However, this places the pilot within striking distance of most of his environment. Practical considerations make it difficult to render the pilot's environment completely non-injurious by padding or shielding. The only efficient approach to this problem is to provide the crew with an adequate restraint system (seat belt and shoulder harness) and to make its use mandatory at all times. It should be noted, however, that the width of the shoulder harness guide on top of the seat back allows the crew member sufficient lateral movement to contact his immediate environment. A narrower guide would reduce this hazard while the wearing of protective helmets would decrease the injurious effects of accidental contact.

Section II

The automatic locking mechanism of the MA-1 inertia reel has unidirectional characteristics; it locks only when subjected to accelerative forces with a component of at least 2-3 G parallel to the longitudinal axis of the aircraft. This is a distinct disadvantage since it will fail to operate in crashes with predominantly lateral or vertical forces.

CONCLUSIONS

Based upon the evaluation of the crew compartment, it is concluded that:

1. The cockpit has several desirable features which reduce the number of objects within striking range of the crew.
2. The stowable radio console would constitute a serious hazard if it became dislodged.
3. The width of the shoulder harness guide on top of the crew seat backs allows too much lateral movement. This may result in serious contact-injury during side load conditions.
4. The fact that the inertia reel locks only when accelerative forces approximately parallel to the longitudinal axis of the aircraft are applied constitutes a hazard.
5. Anchorage of the shoulder harness to the seat structure constitutes a hazard since it tends to overload the seat during a crash deceleration and precludes occupant protection when the seat tie-down fails.
6. Vertical adjustment of the crew seats while a person is supporting himself against the inboard side of these seats may cause hand injuries.
7. The resistance of the crew seats against side and up loads is inadequate.
8. The lack of a seat belt in the "jump" seat would constitute a hazard to the occupant.

Section II

RECOMMENDATIONS

Based upon the foregoing conclusions it is recommended that:

1. The tie-down strength of the radio console in the fore and aft position be subject to a critical examination to determine its compatibility with the tie-down strength of the crew seats.
2. The width of the shoulder harness guide on top of the crew seat backs be reduced to increase lateral support during side load conditions.
3. The inertia reel in the Caribou be replaced by a model that ensures positive locking of the shoulder harness regardless of the direction of crash force.
4. Consideration be given to anchoring the shoulder harness to basic aircraft structure in a manner that precludes undue inconvenience to the crew members.
5. The inboard sides of the crew seats be shielded in a manner that precludes injury to a person supporting himself against these seats.
6. The present ultimate sideward and upward load characteristics of the crew seats be re-evaluated to determine whether these loads are compatible with the forward strength characteristics of the seats.
7. MIL-S-5705 be used as a guide for the "jump" seat installation of the Caribou, including the installation of a seat belt.
8. The use of seat belts, shoulder harness, and protective helmets by crew members be made mandatory at all times.

EVALUATION OF CABIN/CARGO COMPARTMENT

GENERAL

The cargo compartment (Figure 8) is designed for a distributed loading of 200 p. s. f. over the entire area. The floor treadway strength is 2,000 pounds per wheel; floor strength outside the treadway area is 1,000 pounds per wheel.

The floor contains 54 tie-down assemblies consisting of a formed sheet metal pan with a stud to which a troop seat leg may be attached. The sheet metal pan also includes a non-removable, swiveling, flush-folding cargo tie-down ring. The tie-down ring and its attachments are capable of withstanding an ultimate load of 5,000 pounds. In addition, there are 28 tie-down rings in the side walls, slightly above floor level. Four of these are of 10,000 pound ultimate capacity; the balance are of 2,000 pound capacity.

The excellent strength characteristics of the floor as a load-handling and cargo tie-down platform are not fully utilized in the restraint system of cabin occupants, as will be shown in a subsequent chapter.

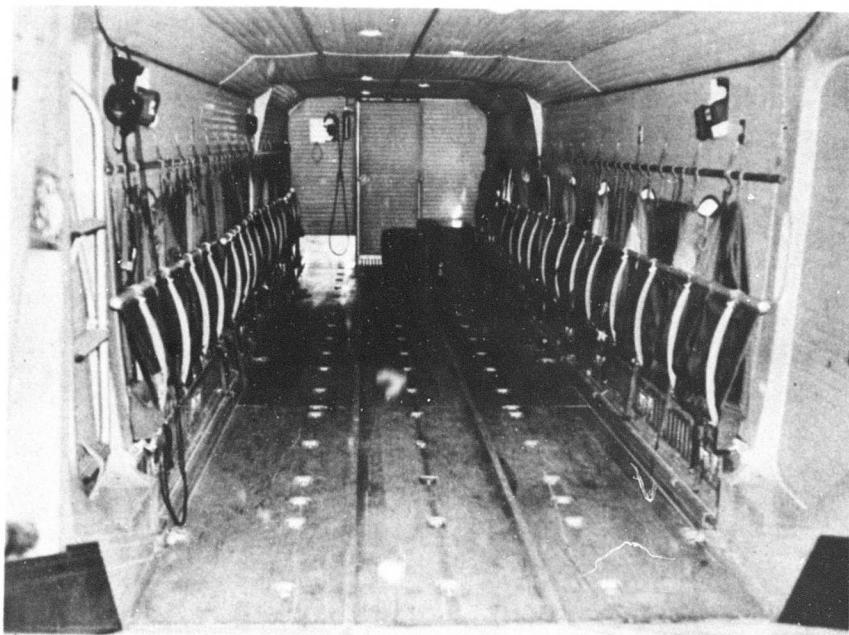


Figure 8. Forward view into the cabin/cargo compartment. The sliding door between cockpit and cabin is closed.

Section III

The cargo compartment is equipped with a large rear cargo door (Figure 9). The lower section of this door serves as a short ramp which can be adjusted to match truck bed height.

The upper section of the cargo door retracts into the roof, permitting a truck to back into the opening. This upper section, which can be operated electrically or manually, is jettisonable.

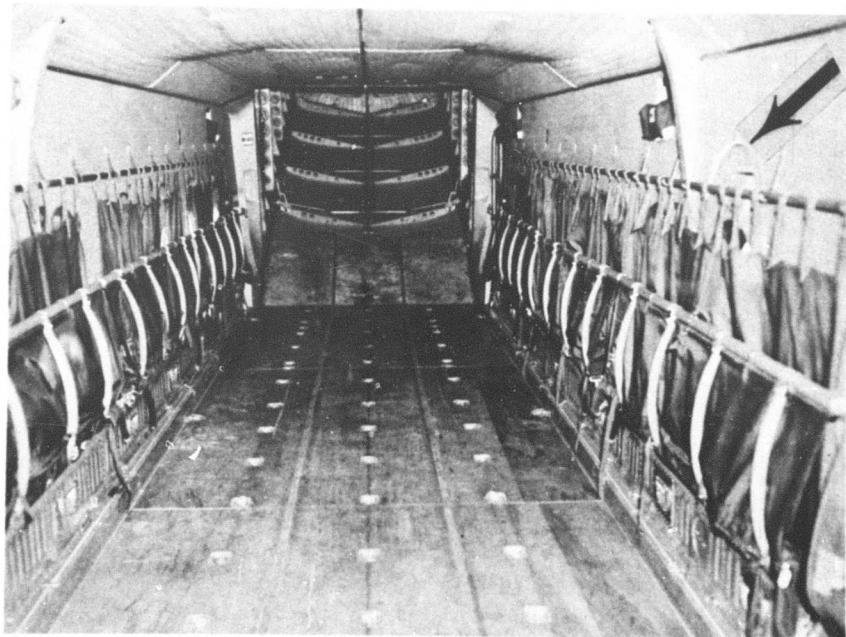


Figure 9. Aft view into the cabin/cargo compartment. The cargo door is closed. The arrow indicates the forward emergency exit.

Two auxiliary ramps, to facilitate loading wheeled vehicles, are stowed against the ceiling in the aft fuselage above the cargo door (Figure 10). It is impossible to make an analysis of the tie-down strength of this installation based upon the available data. It can only be stated that these ramps would create a serious hazard for the cabin occupants if they became dislodged as a result of impact forces or distortion of the aft fuselage.

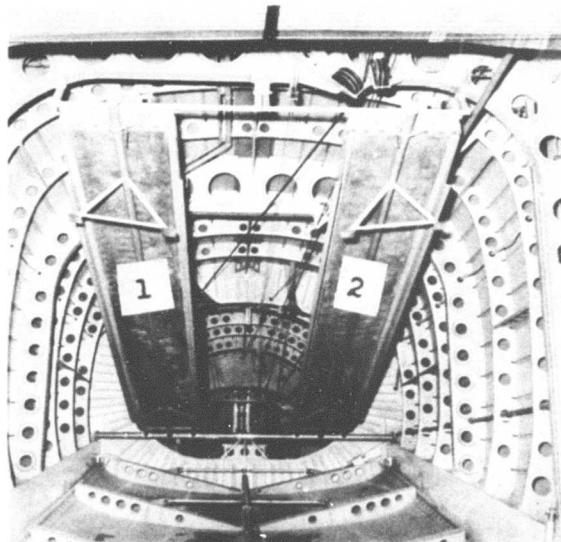


Figure 10. The two auxiliary ramps (1 and 2) are stowed against the ceiling in the aft fuselage above the cargo door.

TROOP SEATS

The aircraft can be equipped with variable width, side facing, standard interchangeable troop seats designed in accordance with Military Specification S-27174 (USAF). * This installation accommodates 32 passengers or 26 combat equipped troops. Variation in seat width is provided by means of adjustable seat belt attachment points. The seat legs are attached to the floor by means of standard quickly detachable recessed stud fittings. (Figure 11) The seats are readily stowable and removable.

The seat frame consists of upper, rear, and front support tubes to which is attached the seat back and seat bottom material (nylon). The seat legs are attached to the front support tube. Spreaders maintain the distance between rear and front support tubes.

* The troop seat in the Caribou does not bear the approval of the Canadian Department of Transport.



Figure 11. Forward view into the cabin showing the four-man troop seats in folded and unfolded position.

Although the Military Specification specifies tape (webbing) material for the seat back, the seat backs in the Caribou consist of one piece (nylon). This will undoubtedly help to prevent snagging of the equipment carried by paratroopers (Figure 12).

Since no data are available on the dynamic strength characteristics of troop seats, a strength analysis must be based upon the static test requirements set forth in the applicable specifications: MIL-S-5804B (24 September 1957) and MIL-S-27174 (8 April 1960). The basic difference between these two troop seat specifications seems to be that the latter incorporates variable seating width features.

Section III

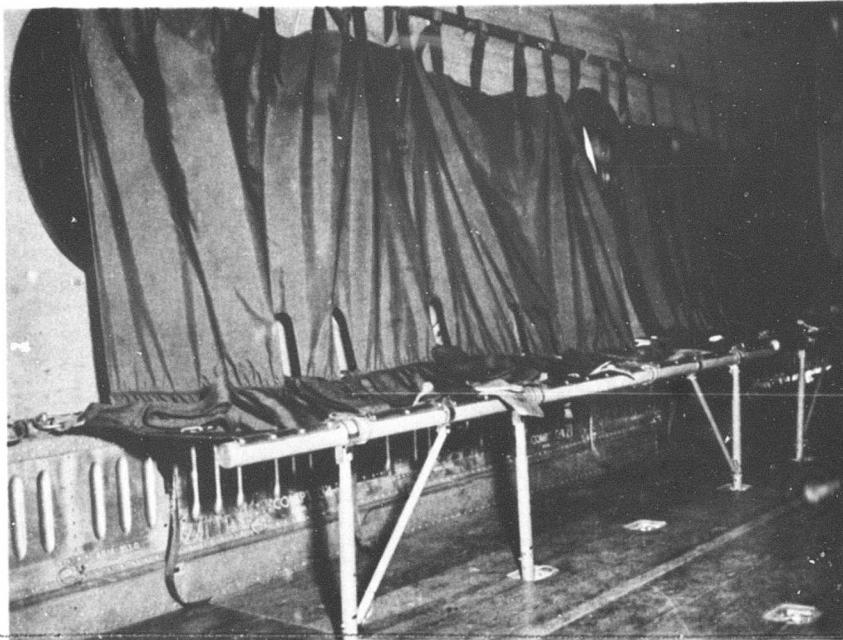


Figure 12. Close-up of a four-man seat. Notice the three legs and their attachment to the floor. The spacing of the holes in the seat back indicates the manner in which variation in seat belt anchorage makes this a variable width seat.

The troop seats must be subjected to, and are required to withstand, the ultimate loads given in Table 2. For convenience, the figures have been converted into G units which are based upon a 200-pound occupant.

TABLE 2
ULTIMATE LOADS (STATIC) FOR SEAT COMPONENTS

	<u>MIL-S-5804B</u>	<u>MIL-S-27174</u>
Seat bottom	11 G	10 G
Seat back	3 G	3 G
Side load	1.1 G	1.1 G

The strength requirements in both specifications are similar, with the exception of the seat bottom (11 G vs. 10 G). The load on the seat bottom may be considered equally distributed over the rear and front support tubes (Figure 13). This leads to some interesting speculations on the loading of the seat legs. According to the specification, the load carrying capacity of these legs is 1,000 pounds each. Making the conservative assumption that not more than half the occupant's weight is supported by the seat legs this would give the legs a 10 G strength. However, for a three-man seat the center leg is optional which implies that the resistance against vertical loads would be reduced to about 6.5 G (2,000). In the same manner the strength of a four-man seat with three legs, as used in the Caribou, would be reduced to 7.5 G.



Figure 13. Close-up showing the load distribution over the front and rear support tubes and seat back. The arrow indicates where the occupant straddles the spreader.

The effect of moderate crash forces on seats of similar design is shown in Figure 14. The seat legs and the front support tube failed in a manner that exposed the occupants to serious injury.

The side load strength requirement for this seat forms the main point of controversy concerning the adequacy of design. The seat is required to withstand an ultimate sideload of 225 pounds (1.1 G) applied in line with the center line of the front support tube. Since the seats are installed alongside the cabin walls (facing inboard), this load is applied parallel to the longitudinal axis of the aircraft and can actually be considered a forward load. In fixed wing aircraft this is often the direction in which a component of the main crash force is applied and for this reason most seats have their greatest strength in the forward direction. The foregoing should make it clear that in the case of the troop seat design requirements the situation is exactly reverse, that is, the seat has its lowest strength in the forward direction.

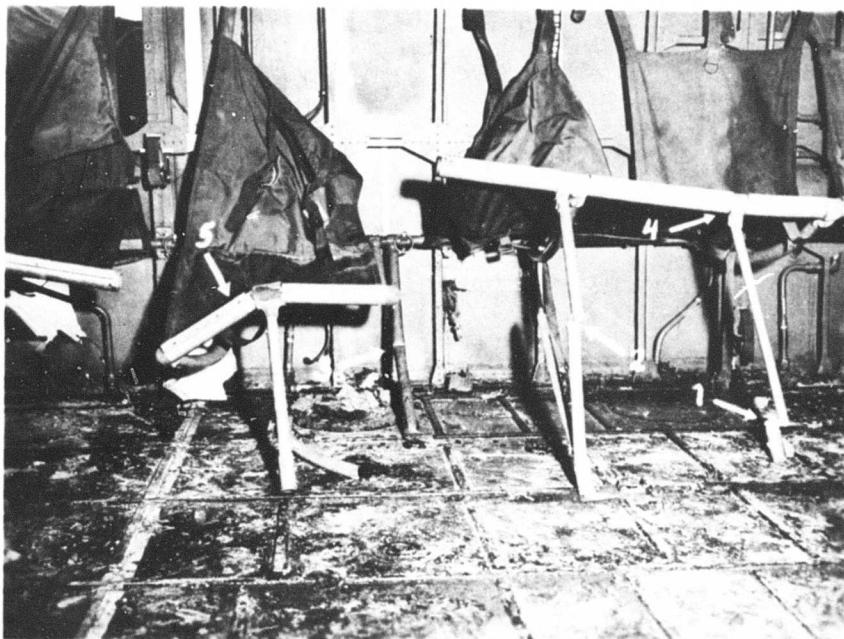


Figure 14. Post-crash appearance of seats built in accordance with the same Military Specifications, installed in another aircraft, after a moderate impact. The arrows indicate failures.

Section III

To further illustrate the inadequacy of troop seat design criteria, a comparison was made between the resultant forward and downward ultimate load requirements for the troop seat, similar requirements for passenger transport seats (NAS 809), litter installations (MIL-S-5705), and the basic structure of cargo/transport aircraft (MIL-S-5705).

By making the favorable assumption that the static loads, which these structures must be able to withstand when applied separately, can also be sustained without failure when applied simultaneously, a more realistic approach to actual seat strength can be made. (See Figure 15.)

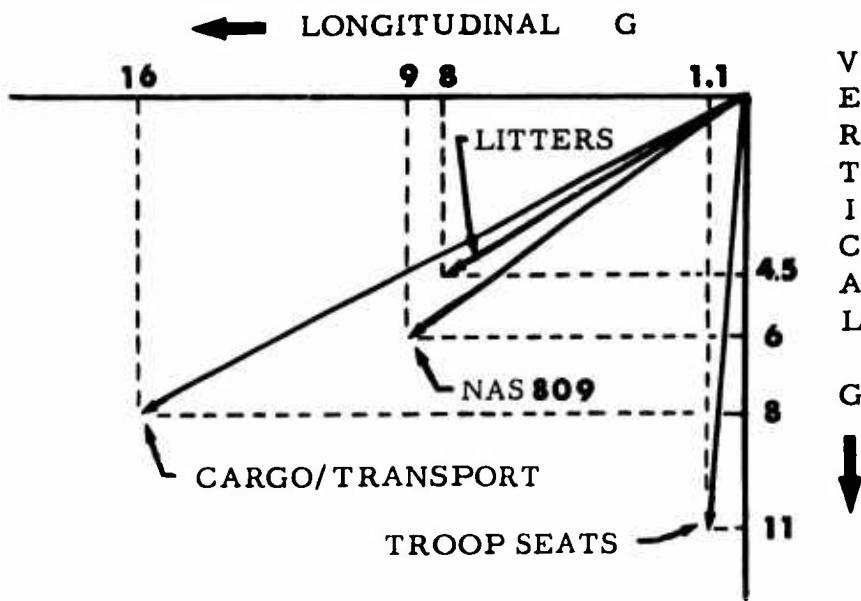


Figure 15. Static ultimate load requirements for seats, structures, and litters.

Section III

In this diagram the longitudinal and vertical load requirements have been combined to show the peak magnitude and optimum direction of crash force resultants sustainable by: Cargo/Transport aircraft structure; litters; passenger seats; and troop seats.

The information in Figure 15 can be tabulated as shown in Table 3.

TABLE 3
STATIC ULTIMATE LOAD REQUIREMENTS FOR SEATS,
STRUCTURES, AND LITTERS

	<u>Resultant ultimate load</u>	<u>Direction of application</u>
1. Cargo/Transport aircraft structure	18 G	27°
2. Litters	9 G	30°
3. NAS 809 (passenger seats)	11 G	35°
4. Troop seats	11 G	85°

To make these data more meaningful the various ultimate load characteristics should be compared under identical conditions of crash force angle. This has been done in Figure 16.

Section III

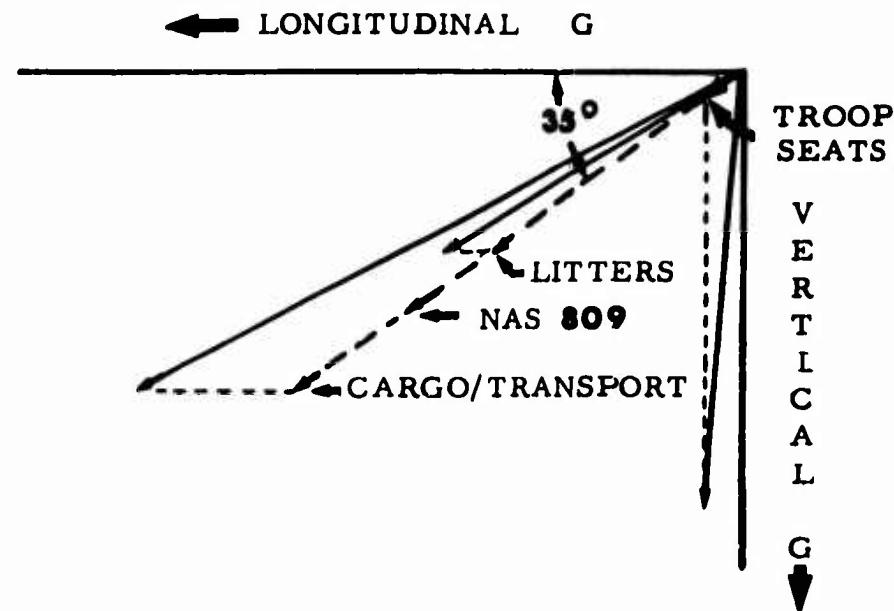


Figure 16. Ultimate load characteristics for seats, structures, and litters at 35° crash force angle.

The resultant ultimate load characteristics of cargo/transport structure, litters, and troop seats have been transposed to a 35° vector, which coincides with the resultant of the NAS 809 passenger seat requirements. This angle was chosen because accident experience seems to indicate that this is an acceptable mathematical average of the directions of crash force application in survivable accidents. The results of this transposition can be summarized as follows: At a crash force angle of 35° the theoretical ultimate load strength of the subject structures is shown in Table 4.

TABLE 4
**THEORETICAL ULTIMATE LOAD STRENGTH OF SEATS, STRUCTURES,
 AND LITTERS AT 35° CRASH FORCE ANGLE**

Troop seats	1.2 G
Litters	8 G
NAS 809 (pass. seat)	11 G
Cargo/transport structure	14.5 G

Table 4 indicates clearly that the crash resistance of the troop seats under anticipated survivable impact conditions is inadequate.

A factor which, to a certain extent, compensates for the lack of adequate forward strength of troop seats is the fact that the seat belt is attached to basic aircraft structure and not to the seat. This seat belt provides protection up to a deceleration of 11 G - (MIL-S-5705). Considering past accident experience, which indicates occasional failure of these seat belts under moderate impact conditions, and the generally accepted assumption that the human G tolerance to abrupt forward deceleration when restrained by a seat belt only, allowing for some minor injuries, is in the 15-20 G range, the required design strength of this seat belt seems inadequate.

The manner in which the seat belts in the Caribou are anchored to basic structure (Figure 17) shows improvement over the anchorages observed in previously evaluated aircraft. The system of the "D" ring and the drilled hole in the rear support tube, which frequently led to failure at these points as indicated by accident experience, is replaced by a clamp around the support tube. At one end this clamp is attached to the basic aircraft structure and at the other end there is a ring for seat belt anchorage.

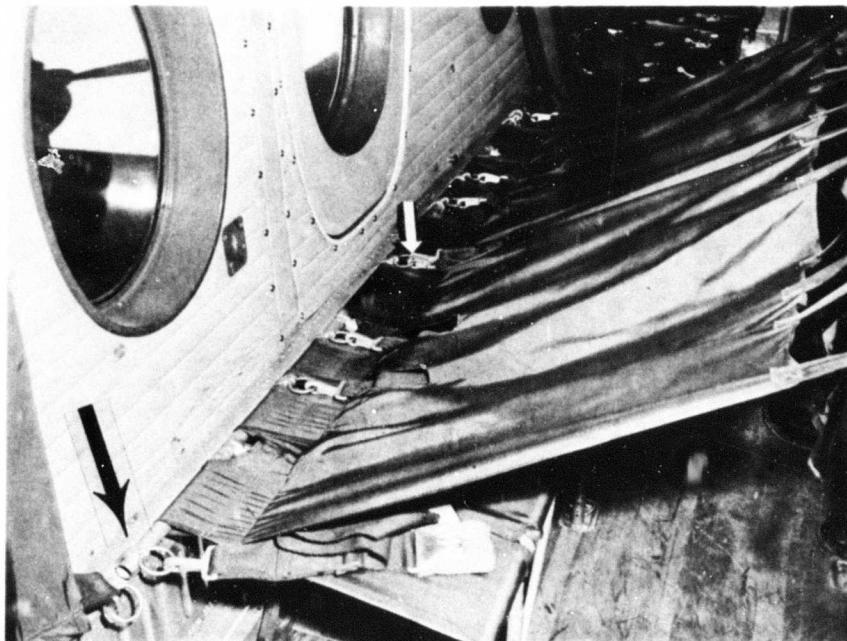


Figure 17. The seat belts in the Caribou are directly attached to the clamps that secure the rear support tube to the basic aircraft structure (black arrow).



Figure 18. Litter and troop seat installations.

Section III

LITTERS

Seven litters, one stack of four and one stack of three, can be installed along both cabin walls (Figure 18). Each litter is mounted in two brackets on the cabin wall and two brackets on litter straps on the aisle side. The litter straps are anchored in the ceiling and in the floor.

Since it is difficult to evaluate the crashworthiness of the entire litter installation without actual dynamic test data and without reliable accident experience, reference can be made only to the applicable specification. MIL-S-5705 states that "Supports and attachment fittings for litters shall be designed so that they carry to the primary structure a 250-pound litter load multiplied by the ultimate load factors in Table 5, acting separately."

TABLE 5
ULTIMATE LOAD FACTORS FOR LITTERS

Forward	8 G
Side	± 1.5 G
Vertical	4.5 G (down) 2 G (up)

This quotation from MIL-S-5705 constitutes all pertinent information available to contractors in connection with the stress requirements of airplane litter installations. There are no quality assurance provisions in the form of certain test requirements and at the date of this report AvCIR was not aware of the existence of static or dynamic test data of this type litter installation.

In addition to being incomplete, these litter tie-down requirements are inadequate. Not only are they far below the recognized limits of human G tolerance (see Appendix I), but they also offer less crash protection than the tie-down requirements for passenger seats in transport aircraft* which are considered inadequate for survivable impact conditions.

The litter installation in the Caribou is not approved by the Canadian Department of Transport.

* NAS 809: (Forward - 9 G; down - 6 G; up - 2 G; side - 3 G)

Section III

CONCLUSIONS

Based upon the evaluation of the cabin/cargo compartment, it is concluded that:

1. The cabin floor forms an excellent platform and will offer considerable crash protection.
2. The two auxiliary ramps, stowed against the ceiling in the aft fuselage, might conceivably become dislodged during a crash deceleration of sufficient magnitude and be hurled into the cabin.
3. The seat belt anchorages in the cabin/cargo compartment show improvement over previously examined installations.
4. The ultimate load requirement of 11 G for the troop seat lap belt (MIL-S-5705) is inadequate. This has occasionally led to belt failures during otherwise moderate impacts.
5. The design requirements for troop seats as specified in MIL-S-5804B and MIL-S-27174 offer the occupants inadequate crash protection, particularly when the seats are subject to side loads. Past accident experience underlines this deficiency.
6. The design requirements for the litter installations as specified in MIL-S-5705 are incomplete and inadequate.

RECOMMENDATIONS

Based upon the foregoing conclusions it is recommended that:

1. The tie-down strength of the auxiliary ramps in the stowed position and the effects of aft fuselage distortion on the present installation be critically examined. (Stowage in the fuselage bottom or sides would simplify the tie-down problem and facilitate ground handling.)
2. The strength of troop seat lap belts and attachments as specified in MIL-S-5705 be increased to approximately 20 G.
3. The present troop seat specifications be subjected to a realistic appraisal in order to determine what steps can be taken to increase occupant protection.

Section III

4. The standard litter installation in Army aircraft, as used in the Caribou, be subjected to static or dynamic tests to (a) determine its ultimate load-carrying capacity in relation to the requirements in MILS-5705; and (b) the adequacy of these requirements in relation to survivable crash force conditions.

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EMERGENCY EXITS

COCKPIT

In addition to the bottom entry hatch, which can be jettisoned, there is an escape hatch in the cockpit structure above and behind the pilot's seat (Figure 19). The sliding windows on both sides of the cockpit provide alternate emergency exits. These arrangements plus the proximity of the cabin emergency exits to the flight crew area are adequate to permit rapid evacuation of the crew. To operate the top escape hatch a button must be pressed before the release handle can be turned. This button is rather small and flush with the surrounding surface. Quick manipulation of this button requires attention and accuracy. In conditions of darkness or crew incapacitation this could easily lead to delay in escape time.

Elimination of this button from the sequence of operation would facilitate operation and does not seem to constitute a hazard because the likelihood of inadvertent operation of this exit in the crew compartment by inexperienced personnel is practically non-existent.

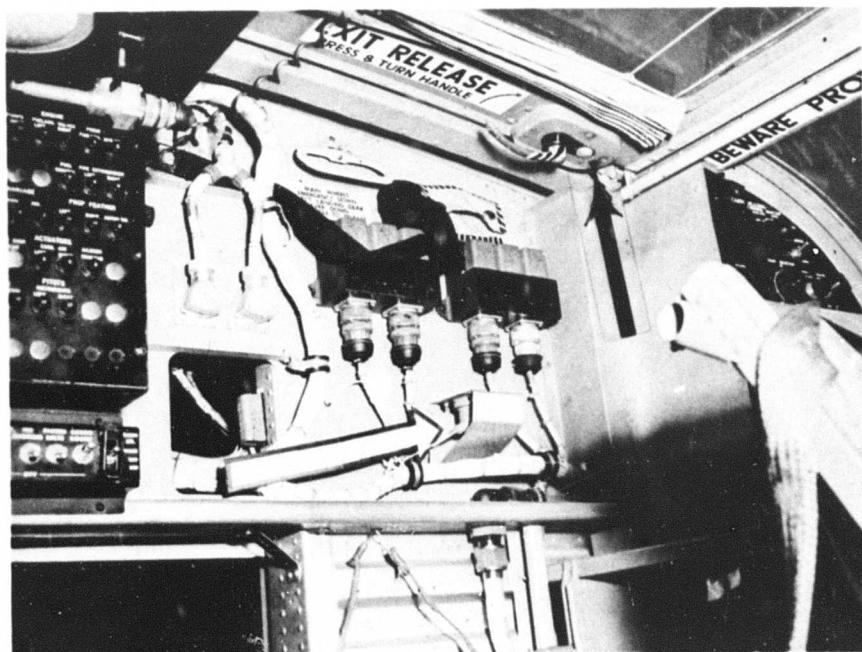


Figure 19. Emergency exit release of the cockpit escape hatch above the pilot's seat. The black arrow indicates the button that has to be pressed before the handle can be turned. Notice that the instructions do not refer to the button.

CABIN

The cabin is equipped with an elliptical emergency exit located on the left side under the left wing. To operate this exit a handle must be turned which is covered by a guard. It will be noted in Figure 20 that this guard cannot be opened unless the upper seat back support tube has been removed. This tube also shields the emergency instructions on the guard. Since the greater part of the emergency exit is covered by the seat backs, it may go unnoticed by less experienced passengers.

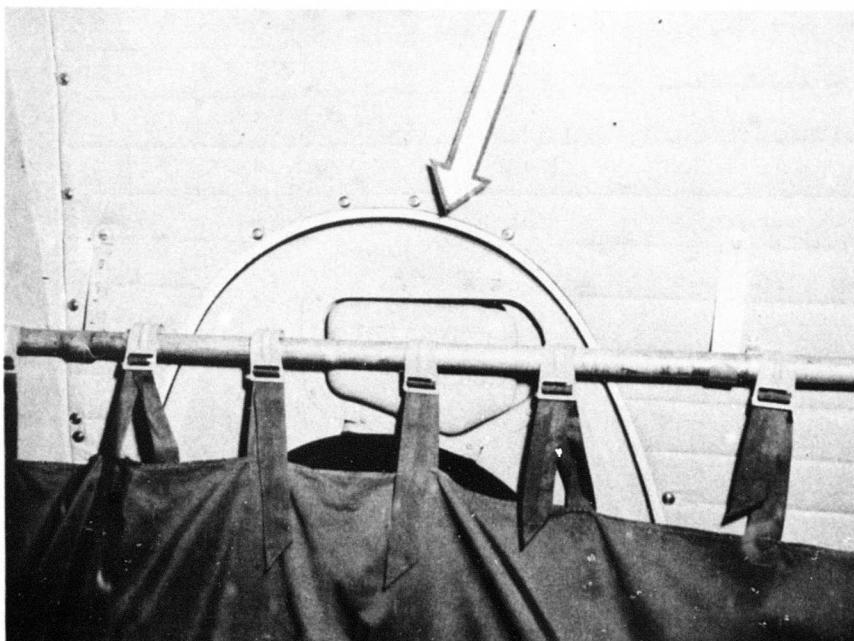


Figure 20. To open the guard covering the exit release of the cabin emergency exit (big arrow), the upper seat support tube has to be removed. This tube also shields the instructions on the guard.

The effectiveness of this emergency exit and the ease of operation would be greatly increased if the open space between adjoining seats had been utilized (Figure 21). In addition, if the location of the exit release handle and guard were slightly changed (up or down) with respect to the upper seat support tube, this exit could be used without removal of seat structure.



Figure 21. The present emergency exit location in the cabin (arrow 1) necessitates removal of the upper seat structure before it can be used. Location of the exit between two adjoining seats (arrow 2) would simplify evacuation.

There are two doors (30 x 50 inches) on opposite sides at the aft end of the cabin (Figure 22). Although the one on the right is jettisonable according to the Model Specification, this was not the case in the model that was examined.

The rear cargo door provides a fourth emergency exit from the cabin compartment (Figure 23). The upper section of this door is jettisonable. The large size of this section and the manner in which it fits in the aft fuselage when in closed position make it very likely that this door will be jammed, when this part of the fuselage is distorted during a crash. Therefore, this door should not be depended upon as an emergency exit unless it is opened or jettisoned before impact. This further indicates the necessity of making both aft exits jettisonable.

If the aircraft came to rest on its left side, two cabin exits might be rendered useless. This, in combination with possible jamming of the cargo door, would leave the cabin passengers with one exit only. The need for an extra emergency exit in the right cabin wall is also indicated in the following extract from the Handbook of Instructions for Aircraft Designers (HIAD - ARDCM 80-1):

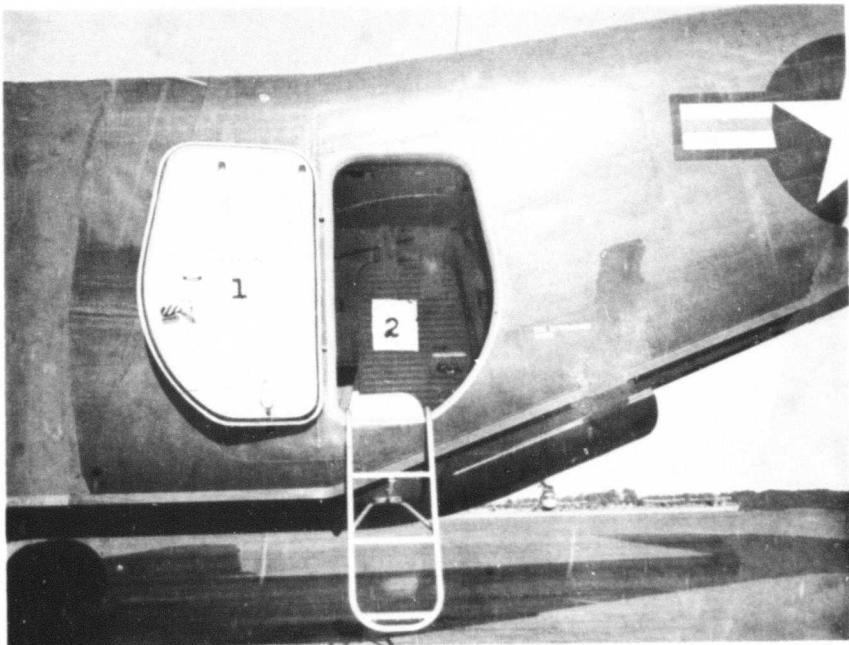


Figure 22. The two doors on opposite sides at the aft end of the cabin (1 and 2) are not jettisonable.

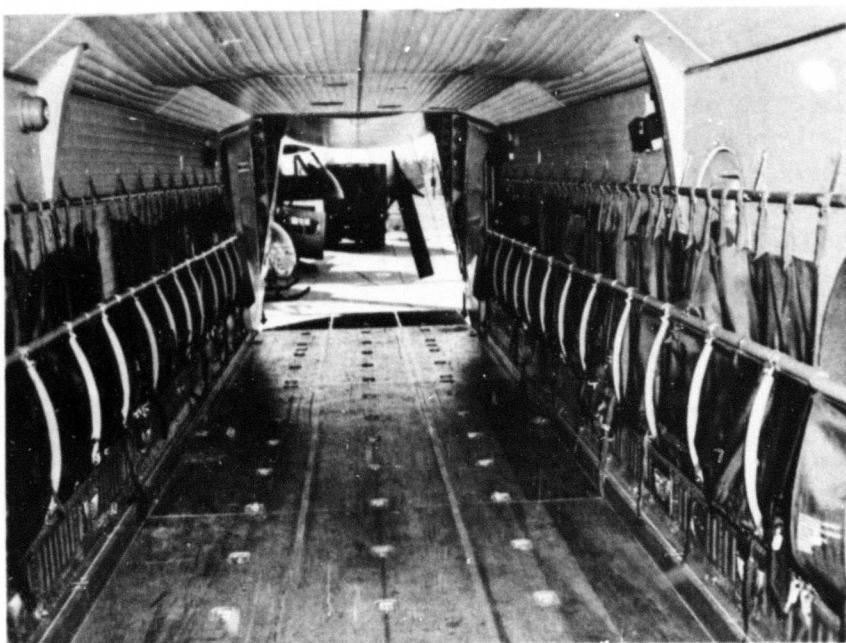


Figure 23. The rear cargo door retracts in the roof structure of the aft fuselage (arrow). It can also be jettisoned.

"Provide all aircraft with a sufficient number of doors, hatches, and emergency exits to permit complete abandonment of the aircraft in the air, on the ground, or in ditching, in 30 seconds by trained personnel representing the crew and all passengers. In addition to the normal openings, clearly and visibly mark areas that can be chopped through with an axe. The number of such areas is dependent upon the number of persons to be evacuated, their disposition in the aircraft, and a probability that 50 percent of the openings will be jammed."

The instructions for the outside release of the emergency exit under the left wing are ambiguous. The instructions read: PRESS AND TURN HANDLE, while an arrow from the word "PRESS" points toward one side of the handle (Figure 24). Actually, the button that must be pressed first is located on the other side of the handle. Since this emergency exit release may be operated by inexperienced rescuers, thought should be given to less ambiguous instructions and a more direct way of operation.

Although elimination of this button would increase the chance of inadvertent operation, this would not be a serious hazard since it can be done only while the aircraft is on the ground.



Figure 24. The instructions for the external operation of the cabin emergency exit under the left wing are inadequate for inexperienced rescue personnel. The arrow under the word PRESS should point towards the button.

Section IV

CONCLUSIONS

Based upon the evaluation of the Emergency Exits, it is concluded that:

1. The number and location of the cockpit emergency exits are adequate.
2. The fact that the operation of the overhead escape hatch in the cockpit and the outside operation of the cabin emergency exit under the left wing requires two separate manipulations may cause delay in evacuation. In addition, the related instructions are ambiguous.
3. The number of emergency exits in the cabin is inadequate, especially when considering the possibility of jamming of the rear cargo door.
4. Use of the forward emergency exit is impeded by the fact that the upper seat support tube must be removed first, while the exit itself and the instructions are partially hidden from view by seat-back structure.
5. An unnecessary hazard is created by the fact that the two exits on opposite sides at the aft end of the cabin are not jettisonable.

RECOMMENDATIONS

Based upon the foregoing conclusions, it is recommended that:

1. The operation of the outside release of the emergency exit and the cockpit escape hatch be simplified by elimination of the button manipulation.
2. If these buttons are to be maintained, the related instructions be made more explicit and leave no doubt regarding sequence of operation and location of button.
3. The doors on opposite sides at the aft end of the cabin be made jettisonable.
4. The relocation of the troop seats with respect to the forward emergency exit (or vice versa) and the exit release handle be considered in order to determine the practicability of making this exit usable without removal of seat structure.

Section IV

5. An extra emergency exit be added to the right cabin wall and that its location and design be governed by Recommendation 4.

Section V

FIRE PROTECTION AND EMERGENCY LIGHTING SYSTEM

FIRE PROTECTION SYSTEM

Both engines, the flight compartment, and cabin heaters have fire detection and extinguishing systems.

Each engine nacelle has an auxiliary and a main firewall which divide each engine compartment into three zones. Each zone has fire detection sensing elements which illuminate warning lights in the cockpit when the temperature reaches 575° F.

The fire extinguishing system consists of two bottles of Freon 13B1 for the protection of zones 2 and 3. The extinguisher can be released by a control handle in the cockpit.

The combustion heaters in the cockpit and the cabin also have a fire detection system which activates a warning light in the cockpit. The heater fire extinguishing system consists of a carbon dioxide (CO₂) bottle incorporated in the mounting tray of each combustion heater. They are operated electrically from the cockpit.

In addition to the fixed fire detection and extinguishing systems, there are provisions for mounting three A20 type hand fire extinguishers; one in the cockpit and two in the cabin.

A guarded switch in the cockpit electrically controls a shut-off valve in the oil supply line to each engine where it passes through the auxiliary firewall. This switch also controls the fuel and hydraulic shut-off valves so that all three valves are closed when the switch is in the ON position.

The location of the fuel cells in the wings outboard of the engine nacelles is considered an excellent crash safety feature since it diminishes the possibility of a post-crash fire and reduces the effects of such an occurrence on the cockpit/cabin compartment.

At the time of the evaluation no data were available on the crash resistance of the fuel cells and the effects of impact on these cells and the fire hazard created by fuel spillage could not be determined.

Section V

EMERGENCY LIGHTING SYSTEM

An emergency lighting system, operating independently of the aircraft electrical system, is provided to illuminate the aircraft exits in the event of a complete electrical failure or a crash.

The emergency lights can be manually operated by a master switch in the cockpit only. This seems inadequate since incapacitation of the crew members could prevent the use of these lights, and thereby delay cabin evacuation.

An impact switch, located on the left side of the monorail near station 327, operates the emergency lights when subject to a forward deceleration of at least 1-1/2 G for 0.033 second.

CONCLUSIONS

Based upon the evaluation of the Fire Protection and Emergency Lighting Systems, it is concluded that:

1. The fire protection afforded as a result of fuel cells being located outboard of the engine nacelles and by the fire detection and extinguishing systems can be further increased if provisions are made for automatic operation of the extinguishing systems under crash loads.
2. The fact that the cabin occupants have no control over the operation of the emergency lighting system constitutes a hazard.

RECOMMENDATIONS

Based upon the foregoing conclusions, it is recommended that:

1. The feasibility of the incorporation of inertia-operated impact switches for the activation of the fire extinguishing systems be investigated.
2. If the installation of individually operable emergency lights is not feasible, consideration be given to the installation of another master switch, similar to the one in the cockpit, near the rear exits of the cabin, and placarded with adequate instructions.

RECAPITULATION OF CONCLUSIONS

The conclusions set forth in this report are:

BASIC AIRFRAME

1. The design criteria and the design achievements are such that adequate crash protection may be expected in non-extreme impacts with landing gear extended.
2. Unflared landing crashes with the landing gear retracted may cause excessive loads on the fuselage structure.

CREW COMPARTMENT

1. The cockpit has several desirable features which reduce the number of objects within striking range of the crew.
2. The stowable radio console would constitute a serious hazard if it became dislodged.
3. The width of the shoulder harness guide on top of the crew seat backs allows too much lateral movement. This may result in serious contact-injury during side load conditions.
4. The fact that the inertia reel locks only when accelerative forces approximately parallel to the longitudinal axis of the aircraft are applied constitutes a hazard.
5. Anchorage of the shoulder harness to the seat structure constitutes a hazard since it tends to overload the seat during a crash deceleration and precludes occupant protection when the seat tie-down fails.
6. Vertical adjustment of the crew seats while a person is supporting himself against the inboard side of these seats may cause hand injuries.
7. The resistance of the crew seats against side and up loads is inadequate.
8. The lack of a seat belt in the jump seat would constitute a hazard to the occupant.

CABIN/CARGO COMPARTMENT

1. The cabin floor forms an excellent platform and will offer considerable crash protection.
2. The two auxiliary ramps, stowed against the ceiling in the aft fuselage, might conceivably become dislodged during a crash deceleration of sufficient magnitude and be hurled into the cabin.
3. The seat belt anchorages in the cabin/cargo compartment show improvement over previously examined installations.
4. The ultimate load requirement of 11 G for the troop seat lap belt(MIL-S-5705) is inadequate. This has occasionally led to belt failures during otherwise moderate impacts.
5. The design requirements for troop seats as specified in MIL-S-5804B and MIL-S-27174 offer the occupants inadequate crash protection, particularly when the seats are subject to side loads. Past accident experience underlines this deficiency.
6. The design requirements for the litter installation as specified in MIL-S-5705 are incomplete and inadequate.

EMERGENCY EXITS

1. The number and location of the cockpit emergency exits are adequate.
2. The fact that the operation of the overhead escape hatch in the cockpit and the outside operation of the cabin emergency exit under the left wing requires two separate manipulations may cause delay in evacuation. In addition, the related instructions are ambiguous.
3. The number of emergency exits in the cabin is inadequate, especially when considering the possibility of jamming of the rear cargo door.
4. Use of the forward emergency exit is impeded by the fact that the upper seat support tube must be removed first, while the exit itself and the instructions are partially hidden from view by seat-back structure.

5. An unnecessary hazard is created by the fact that the two exits on opposite sides at the aft end of the cabin are not jettisonable.

FIRE PROTECTION AND EMERGENCY LIGHTING SYSTEM

1. The fire protection afforded as a result of fuel cells being located outboard of the engine nacelles and by the fire detection and extinguishing systems can be further increased if provisions are made for automatic operation of the extinguishing systems under crash loads.
2. The fact that the cabin occupants have no control over the operation of the emergency lighting system constitutes a hazard.

RECAPITULATION OF RECOMMENDATIONS

The recommendations set forth in this report are:

BASIC AIRFRAME

Based upon the conclusions regarding the basic airframe, it is recommended that:

1. If conditions permit, crash landings be made with the landing gear extended, regardless of the terrain used.
2. If landing gear malfunction dictates a wheels-up landing, flat terrain be selected and the landing technique be aimed at minimum vertical load at touchdown.

CREW COMPARTMENT

Based upon the conclusions regarding the crew compartment, it is recommended that:

1. The tie-down strength of the radio console in the fore and aft position be subject to a critical examination to determine its compatibility with the tie-down strength of the crew seats.
2. The width of the shoulder harness guide on top of the crew seat backs be reduced to increase lateral support during side load conditions.
3. The inertia reel in the Caribou be replaced by a model that ensures positive locking of the shoulder harness regardless of the direction of crash force.
4. Consideration be given to anchoring the shoulder harness to basic aircraft structure in a manner that precludes undue inconvenience to crew members.
5. The inboard sides of the crew seats be shielded in a manner that precludes injury to a person supporting himself against these seats.

6. The present ultimate sideward and upward load characteristics of the crew seats be re-evaluated to determine whether these loads are compatible with the forward strength characteristics of the seats.
7. MIL-S-5705 be used as a guide for the "jump" seat installation of the Caribou, including the installation of a seat belt.
8. The use of seat belts, shoulder harness, and protective helmets by crew members be made mandatory at all times.

CABIN/CARGO COMPARTMENT

Based upon the conclusions regarding the cabin/cargo compartment, it is recommended that:

1. The tie-down strength of the auxiliary ramps in the stowed position and the effects of aft fuselage distortion on the present installation be critically examined. (Stowage in the fuselage bottom or sides would simplify the tie-down problem and facilitate ground handling.)
2. The strength of troop seat lap belts and attachments as specified in MIL-S-5705 be increased to approximately 20 G.
3. The present troop seat specifications be subjected to a realistic appraisal in order to determine what steps can be taken to increase occupant protection.
4. The standard litter installation in Army aircraft, as used in the Caribou, be subjected to static or dynamic tests to (a) determine its ultimate load-carrying capacity in relation to the requirements in MIL-S-5705; and (b) the adequacy of these requirements in relation to survivable crash force conditions.

EMERGENCY EXITS

Based upon the conclusions regarding the emergency exits, it is recommended that:

1. The operation of the outside release of the emergency exit and the cockpit escape hatch be simplified by elimination of the button manipulation.

2. If these buttons are to be maintained the related instructions be made more explicit and leave no doubt regarding sequence of operation and location of button.
3. The doors on opposite sides at the aft end of the cabin be made jettisonable.
4. The relocation of the troop seats with respect to the forward emergency exit (or vice versa) and the exit release handle be considered in order to determine the practicability of making this exit usable without removal of seat structure.
5. An extra emergency exit be added to the right cabin wall and that its location and design be governed by Recommendation 4 above.

FIRE PROTECTION AND EMERGENCY LIGHTING SYSTEMS

Based upon the conclusions regarding the fire protection and emergency lighting systems, it is recommended that:

1. The feasibility of the incorporation of inertia-operated impact switches for the activation of the fire extinguishing systems be investigated.
2. If the installation of individually operable emergency lights is not feasible, consideration be given to the installation of another master switch, similar to the one in the cockpit, near the rear exits of the cabin, and placarded with adequate instructions.

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Appendix I

CRASH SAFETY CRITERIA

In its efforts to determine the crash survival aspects of aircraft accidents AvCIR, a Division of the Flight Safety Foundation, is guided by certain criteria which it considers fundamental for the crash protection of aircraft occupants. The same criteria are also used to evaluate the crash safety features of mock-ups and prototypes.

CRASHWORTHINESS

Crashworthiness may be defined as the ability of basic aircraft structure to provide protection to occupants during survivable impact conditions. Impact conditions are considered survivable in that part of the cockpit/cabin area where the crash forces are within the limits of human tolerance (with minimal or no injury)* and where surrounding structure remains reasonably intact.

Lack of crashworthiness, generally, indicates that the basic aircraft structure, seen as a protective container, is subject to extensive inward collapse thereby affecting the "inhabitability" of this area. Typical in this respect are (1) the rearward movement of the engine in single engine aircraft; (2) the downward displacement of transmissions and other heavy components in helicopters; (3) the upward collapse of lower structures into the cockpit/cabin area. This deformation or collapse of the occupiable area may result in crushing type injuries or trapping of the occupants.

When evaluating the crashworthiness of basic aircraft structure, stress is placed upon the expected behavior of this structure during a survivable type impact. Attention is also given to anticipated dynamic response under the most probable conditions of impact angle and aircraft attitude, based upon accumulated past experience. This facilitates an appraisal of the possibility of displacement of certain heavy components into the occupiable area as a result of inertia forces.

* Approximately 40 G transverse to the spine, 25 G parallel to the spine (positive G), 15 G parallel to the spine (negative G) with due consideration for peak magnitude, duration, rate of onset, and method of body restraint. J. P. Stapp, Human Exposure to Linear Deceleration, Part 2. The Forward-Facing Position and the Development of a Crash Harness. Wright Air Development Center, Wright-Patterson Air Force Base, Dayton (Ohio), December 1951. A. F. Technical Report No. 5915, Part 2.

Appendix I

TIE-DOWN CHAIN

Although a crashworthy structure provides primary protection during a crash deceleration, injuries may still occur when occupants are allowed to come into forceful contact with their environment or to be struck by loose objects thrown through the occupiable area. The restraint system used to prevent occupants, cargo, and components from being thrown loose within the aircraft is commonly referred to as the tie-down chain. The occupant's tie-down chain consists of: seat belt, seat belt anchorage, shoulder harness and anchorage, seat structure, seat anchorages, and floor. Failure of any link in this chain results in a higher degree of exposure to injury.

Accident statistics indicate that the site of most serious and frequent injury in general aviation accidents is the head. In most cases, this is due to lack of restraint, allowing the head to gain momentum during impact and to strike objects in its path with a force exceeding that of the overall crash deceleration. This is especially true in the case of cockpit occupants who face the instrument panel, control wheel, and many other injurious environmental structures. Considering these factors, it is practically impossible to avoid contact injuries during crash deceleration when such occupants are not restrained by a properly installed and properly used shoulder harness of adequate strength in combination with a seat belt.

Although seat structure and anchorages meet static strength tie-down requirements, failures frequently occur as a result of dynamic loads imposed by the occupants on seat belts and shoulder harnesses when these are anchored to the seats instead of primary structure. This type of crash force amplification should be taken into consideration when evaluating the dynamic strength of the occupant tie-down chain. Inadequately or improperly secured aircraft equipment and components in the occupiable area also have an injury potential during crash decelerations. Therefore, the tie-down and stowage of such items as luggage, cargo, radio equipment, fire extinguishers, and tool boxes requires careful consideration.

OCCUPANTS' ENVIRONMENT

Accident experience has shown that under many impact conditions occupants who are reasonably restrained within a crashworthy structure may still receive injuries through forceful contact with injurious environmental structures, components, etc. (This is particularly true when shoulder harness is not used.) The freedom of movement of the

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occupant's body during a crash deceleration is governed by the type of restraint system installed and the manner in which it is used. Generally, it can be stated, however, that injuries resulting from the flailing action of the occupant's body show a peripheral trend; that is, the areas farthest away from the seat belt receive most of the injuries (head and lower extremities).

To preclude the probability of injury through striking injurious environment, the limitations of the restraint system should be used as a guide for the extent to which the occupant's environment should be made harmless. The injury potential of all objects and structure within striking range, omni-directionally, can be reduced to a minimum by such measures as elimination of sharp surfaces, safety-type control wheels, breakaway features in instrument panels, use of ductile or energy absorbing material wherever possible.

TRANSMISSION OF CRASH FORCE

Another independent injury-producing factor presents itself in the fact that crash forces may be transmitted or even magnified through rigid aircraft structures. This is usually associated with "bottoming out" on structures incapable of absorbing or reducing crash force. Although crash force in most accidents is applied in a direction oblique to the occupant's spine, it is customary to resolve vertical and horizontal components of the crash force resultant and relate these to the human G-force tolerance levels, either parallel or transverse to the spine. A normally seated person, when effectively restrained by a seat belt and shoulder harness, can tolerate (with minimal or no injury) approximately 40 G transverse to the spine, 25 G parallel to the spine in the foot-to-head direction (positive G), 15 G parallel to the spine in the head-to-foot direction (negative G).

Injuries attributed solely to transverse G will seldom be encountered in aircraft accidents, because collapse of structure and/or failure of the restraint system will most likely occur before the limit of transverse G tolerance (40 G) is reached. This is an undesirable situation. Although operational and economic considerations impose limits on the overall fuselage strength, the occupant tie-down chain should be more compatible in strength with tolerance levels of the body.

Accident experience has shown that injuries directly attributed to the transmission or magnification of crash force are usually associated with predominantly vertical impacts. Vertebral injuries are most often associated with vertical crash force application.

Appendix I

The seat, as the occupant's supporting structure, and the underlying floor structure are the media through which vertical forces are usually transmitted to the occupant. The dynamic response of these media during an impact determines the manner in which the forces acting on the aircraft structure can be modified before reaching the occupant. An extremely rigid structure, which normally is not found in aircraft, would transmit the forces without modification. An elastic structure, which has energy-storing properties, may modify the magnitude and other characteristics of decelerative force to the extent that amplification takes place. For example, a foam rubber cushion (which does not offer an appreciable resistance to compression) allows an occupant to "bottom out" against rigid seat and seat pan structures during a vertical impact. A more desirable situation would be that in which the structure between the occupant and the point of impact had high energy absorbing characteristics. This may be achieved by the use of structure which collapses progressively without failing suddenly. This ideal form of crash energy absorption results in attenuation of the crash forces transmitted to the occupant. It is one of the basic methods for the incorporation of occupant protection in aircraft design.

POST-CRASH FACTORS

Although a distinction could be made between the prevention of injuries sustained in the dynamic phase of the impact and those sustained in the post-crash events, it is felt that the overall crash survival concept does not allow this distinction. Past experience has shown that accidents involving only very minor impact forces can become catastrophes as a result of post-crash factors.

One of the greatest hazards in an otherwise survivable accident is the possibility of a post-crash fire. These fires, normally, are of a sudden nature and may severely restrict the time available for evacuation. According to a NACA study (Technical Note 2996) not more than 50 seconds may be available for escape in all but the most severe fires, although in some cases passengers must move away from areas of burned-through fuselage in as few as 7-1/2 seconds. This time element becomes even more critical when occupants are handicapped by such factors as disabling injuries, stunned condition, unfamiliarity with the seat belt release or the operation of the emergency exits, being trapped, and panic.

Control of post-crash fires, to some extent, is governed by design (location of fuel cells and fuel lines in relation to electrical and mechanical ignition sources; resistance of fuel system components against rupture

Appendix I

under conditions of moderate crash forces or distortion). Other preventive measures include location of fire extinguishers at strategic points and automatic emergency or impact-operated fire extinguishing systems.

In the event of a post-crash fire or a ditching, the ability of all occupants to timely evacuate the aircraft probably becomes the most important survival factor. The evacuation time is a function of the number, location, and adequacy of the normal and emergency exits. * The location and emergency operation of normal and emergency exits should be obvious even to the non-experienced passenger. Hand or impact-operated emergency lights can be of vital importance during evacuation in conditions of darkness or subdued light.

* HIAD (the military Handbook of Instructions for Aircraft Designers) requires "a sufficient number of doors, hatches, and emergency exits to permit complete abandonment of the aircraft in the air, on the ground, or in ditching, in 30 seconds by trained personnel representing the crew and all passengers."

APPENDIX II
DESIGN REQUIREMENTS FOR AIRCRAFT STRUCTURE
AND VARIOUS SEATS

DESIGN REQUIREMENTS FOR AIRCRAFT STRUCTURE AND VARIOUS SEATS

LOAD DIRECTION	A/C STRUCTURE CARGO/TRANSP. MIL-S-5705	PILOT SEATS		PASSENGER SEATS (TRANSPORT)		
		CARIBOU D. H. DESIGN	TYPE A-10 MIL-S-5822	CAM 4b	NAS 809 MIL-S-5804	TROOP SEAT
FORWARD	16 G	20 G	11 G	9 G	9 G	1.1 G*
DOWNDWARD	8 G	7 G	15 G	4.5 G	6 G	11 G
UPWARD	4 G	3 G	7.5 G	2 G	2 G	NA **
SIDEWARD	4 G	3 G	10 G	1.5 G	3 G	1.1 G*

* When the seat is installed along the cabin wall, the sideward load requirement is indicative of the forward strength.

** Since the seat belt is attached to basic aircraft structure, there is no upward load requirement for troop seats.

Appendix II